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Energy Systems Group Annual Progress Report 1 January - 31 December 1982 June 1983

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Edited by
Gordon A. Mackenzie and Hans Larsen

Risø National Laboratory, DK-4000 Roskilde, Denmark
June 1983

CONTENTS

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ENERGY SYSTEMS GROUP

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Abstract. The report describes the work of the Energy Systems Group at Risø National Laboratory during 1982. The activities may be roughly classified as Danish energy planning, development and application of energy-economy models and technical-economic analyses of specific parts of the Danish energy system. A brief description of recently started projects is given and the report concludes with a list of the staff members, including experience and areas of interest within the group.

EDB descriptors: DENMARK; ENERGY ANALYSIS; ENERGY DEMAND; ENERGY MODELS; HEATING; PLANNING.

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1. INTRODUCTION

During the last five years the Energy System Group (ESG) at Risø National Laboratory has developed extensive experience in the fields of energy-economy modelling, energy planning, and technical-economic analysis of energy systems. The nature of these studies generally requires a wide background of knowledge covering economic modelling techniques, public planning, the interelationship of various components of the energy system, as well as the details of individual energy supply technologies.

The programmes of the Energy Systems Group involve basic R&D, work for and in collaboration with public authorities, as well as activities carried out under contract with various organisations in Denmark and abroad.

One of the main undertakings of the group in recent years has been its participation in the work on the Danish Energy Plan (EP-81) which was published at the end of 1981 by the Danish Ministry of Energy (1). In 1982 this was followed by a number of projects such as the updating of the DES-model on the basis of the experience gained during the work with the Energy Plan, and a study concerning the possible introduction of small- and medium-size coal installations in the Danish Energy System. Furthermore, an investigation has been started on the long-term prospects of energy technologies, up to the year 2030, with special emphasis on trends in the development of those post-2000 energy technologies that may have an important impact on the decisions to be made in this century.

A number of internal research and development projects have been undertaken. Apart from the work on the DES-model already mentioned, these projects primarily take the form of postgraduate research studies. For examples a model for the simulation of combined heat and power production is under development and will be completed in 1983. Another postgraduate project being carried out is that concerning pricing policies and tariff structures. A final study in this category is the one on the economic assessment of energy technologies involving sensitivity and uncertainty analysis.

The work on the energy-economy model was dominated by the modelling programme of the Commission of the European Communities (CEC). The work is carried out in close collaboration with the other member nations of the European Community. The work in 1982 has primarily been centred around the macrosectoral model, now called HERMES, and the long-term energy demand model, MEDEE.

In addition to the activities mentioned above, various studies have been carried out under contract. A preproject was carried out for the Nordic Council of Ministers with the aim of identifying potential areas for extended Nordic collaboration in the energy sector. Paralleling this a Nordic heat supply study was begun. These studies were carried out as joint ventures of the four Nordic Energy Research Institutes. A preproject concerning the introduction of windmills into an electricity supply system based on diesel generators and hydropower was carried out under the auspices of the Nordic Co-operative Organization for Applied Research (NORDFORSK). Finally, the Energy Systems Group participated in an assessment of the technical and economic prospects for wind energy in the EEC countries.

A great deal of the above-mentioned work involves the processing of large amounts of statistical data pertaining to the energy consumption, economic activity, etc. of the various sectors of society. The establishment and maintenance of such databases and the development of computer software for data retrieval and processing is a most important basic activity of the group.

The work of the Energy Systems Group involves collaboration with other organisations in Denmark such as the electrical utilities, The Danish Ministry of Energy, The Danish Energy Agency and the Universities. Within the Scandinavian Countries ESG collaborates closely with the other Nordic energy research

institutes. Internationally, ESG is involved in collaboration with the CEC and a number of other international organisations together with various research laboratories and universities.

2. DANISH ENERGY PLANNING

The work of the group during 1982 in the area of Danish Energy Planning consisted of a number of projects which extended from Energy Plan 81 (1), one of the group's main activities in 1981.

2.1. Small- and medium-size coal installations

The increased use of coal plays an important role in Danish energy planning and energy research programmes. Examples from the latter are the studies of different coal burning technologies, coal classification, and coal transportation.

The aim of the project was to illustrate some technical and economic consequences of the introduction of small and medium-size coal installations into the Danish energy system, i.e. the change from oil to coal in industry and district heating. The project was carried out as a collaborative effort among the Danish Boiler Owners' Association, The Danish District Heating Association, and Risø, the latter represented by ESG. The study was completed by the end of 1982, and a report was published in 1983.

A conclusion of the study is that most industrial firms which could benefit from a change from oil to coal have already made the transition. As far as the rest of industry is concerned, the expected load factor for a coal-fired boiler is so low, that the savings from the cheaper fuel would be too limited to justify the investment economically.

On the other hand the net savings which can be obtained by a coal-fired district heating plant producing mainly base-load heat may give a payback time on the investment of less that 2 years, except for the smallest units with capacities less than 3 MW. The load factor of a coal-fired unit, however, is very dependent on how the unit is phased into the local energy system.

The potential market for coal in district-heat production depends on the future structure of district heating in Denmark. In 1980 oil-fired district heating covered about 25 per cent of the demand for space heating and domestic hot water. However, according to the Danish Heat Plan more than two thirds of this potential market for coal-fired district heating will be transferred to combined heat and power, waste heat or natural gas during the next 10-15 years. Taking this into account, the study concludes that eventually 3-6% of the total annual Danish heat demand may be supplied by coal-fired district heating.

The district heating system in a small town consists of a grid and one plant. In larger towns there may be more plants with partially connected grids, and there are often alternative means of heat supply, e.g. a waste incineration plant. A single coal-fired unit which is phased into a small area might be given a capacity of 60% of the total heat load and produce 90% of the heat demand. The remaining 10% must be produced by oil at existing boilers that are kept for peak load and reserve. In larger district heating areas two or more units may serve as reserve for each other during the annual maintenance in the summer period when the load is low. In some areas during the summer there may be alternative supplies of fuel e.g. natural gas, or heat e.g. waste heat in areas partially connected to a waste-incineration plant or to a CHP-station.

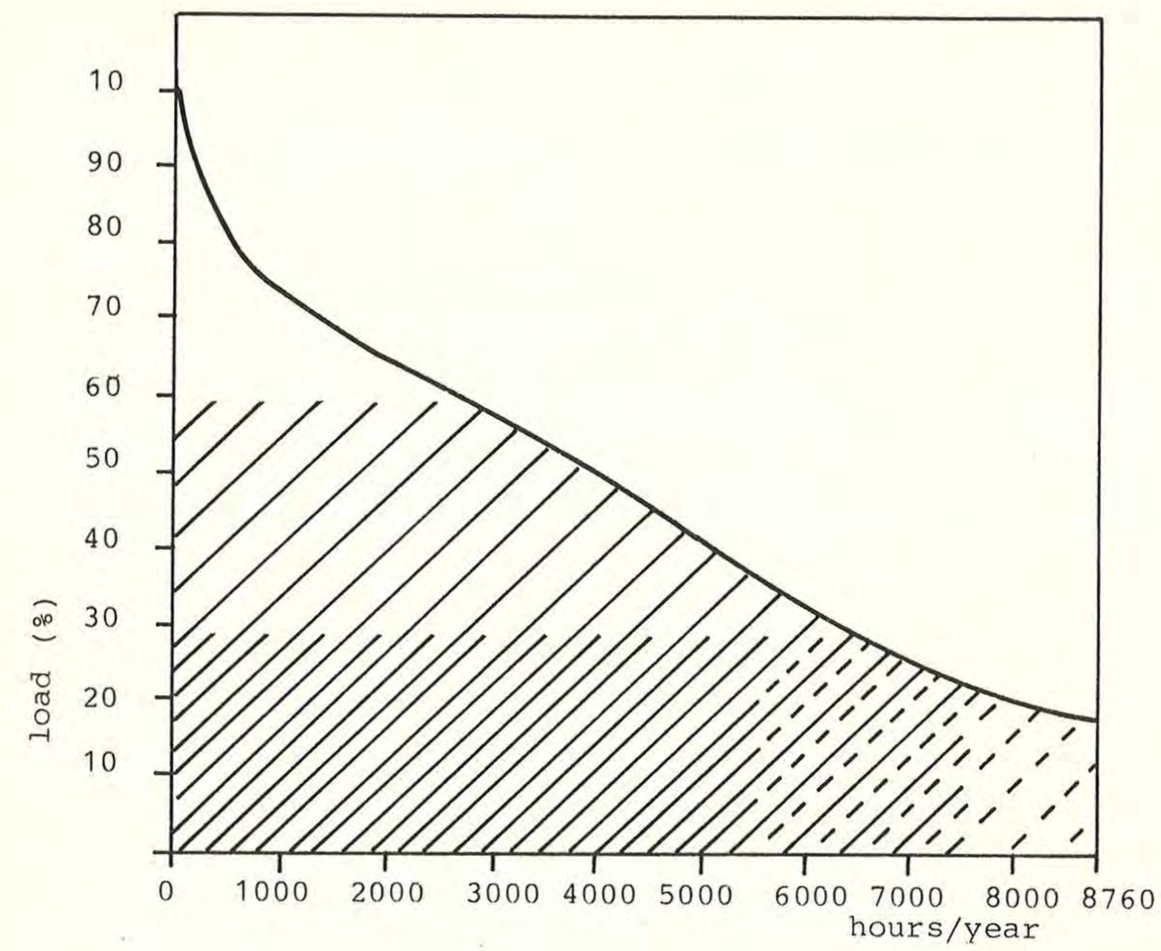


Fig. 2.1. The load duration curve for district heating areas with the phasing in of coal fired units indicated.

2.2. Long-term prospects of energy technologies

In 1982 ESG embarked on a study of the long-term prospects for technological development with relevance to the Danish energy sector. The study is being carried out for the Danish Ministry of Energy as a follow up to the Danish Energy Plan (EP-81) issued in 1981[1].

The study covers the period up to the year 2030. The justification for attempting to study the situation at such a distant future is that the energy system consists predominantly of installations with construction times of up to ten years and expected lifetimes of 25-30 years. Examples of such installations are power plants and natural gas networks. The main emphasis of the study is on the identification and characterisation of the major trends and interdependencies in the development of energy technologies after 2000 which rely heavily on the decisions to be made before then. The study embraces energy-demand and energy-supply technologies, as well as non-energy technologies which could change the demand pattern. Examples of the latter technologies are those concerned with communication and regulation.

An attempt is made to evaluate the various individual candidate technologies by examining a number of technical and economic factors. In addition the study investigates the possibilities for new combinations of energy systems. The reason for this is that it is envisaged that new combined production might well be an important area for future improvements in energy utilisation.

In the period up to the year 2000 major investments are to be made in the Danish natural gas and district heating distribution systems. It is therefore natural that the study focus on technologies which are important to these systems. The question of centralised as opposed to decentralised energy conversion is a matter of great interest, as are the prospects for the development of efficient energy storage facilities and the use of renewable energy sources.

Although the main emphasis of the study is the technological development in the energy sector, it is quite obvious that this development is strongly influenced by the general development in society at large. Figure 2.2. illustrates the idea that technological development is influenced by the development in world energy prices, energy demand in various sectors, etc.

The main outcome of the study will be a number of recommendations for areas where it is important to take account of the expected technological development at an early stage.

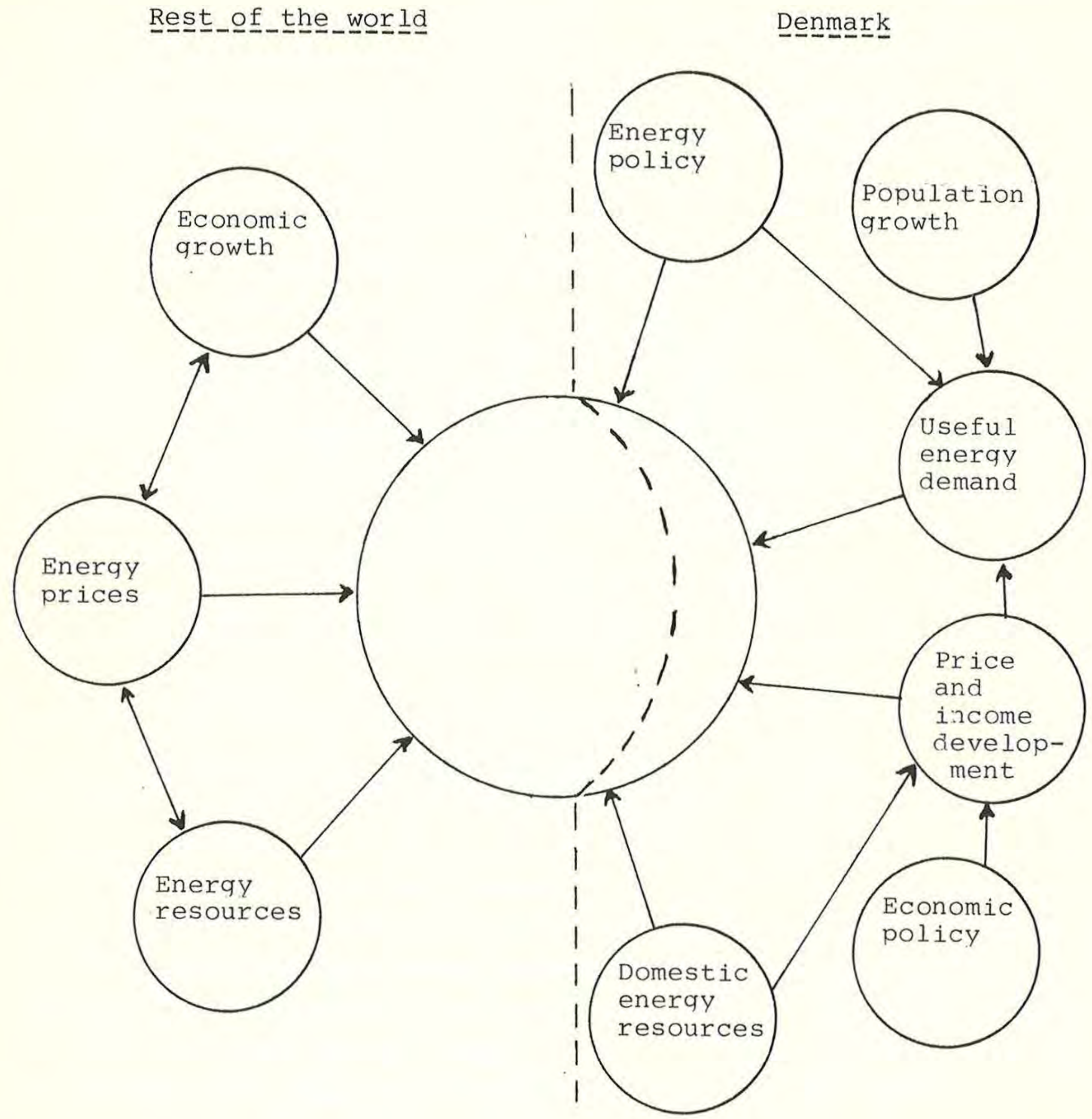


Fig. 2.2. Factors influencing technological development.

2.3. Work for the Ministry of Energy

ESG collaborates closely with the Danish Ministry of Energy, and during the past year the group has been involved in several projects at various levels of participation. Only a few of these activities will be mentioned here.

2.3.1. Energy Report 83

According to law the Minister of Energy must make a report to the parliament at regular intervals concerning the supply and consumption of energy in Denmark. The latest report of this kind called Energy Report 83 (ER 83) is expected to be published in the spring of 1983.

ESG participates in a number of ER 83 working groups formed by the Ministry to study the possible future trends of energy prices, the cost of power plants, both nuclear and conventional, and the cost of electricity production.

2.3.2. Space Heating in Area IV

ESG is currently involved in a study of the space heating forms in the so-called area IV, the parts of the country scheduled to receive neither natural gas nor CHP-generated district heating. At the end of 1982 the Ministry of Energy set up two working groups to study space heating in general and electricity.

The scope of work of the heating group includes the demarcation of area IV and the description of expectations for the future development of this area, with regard to demographic conditions, local energy resources and housing stock. The latter takes into account age, type, location, and heating equipment. Existing and future demand for heat for each single type of building will be estimated, and the different energy supply technologies described. Finally, the different heat supply structures will be evaluated, especially with respect to economy, employment and environmental aspects.

The work in the electricity group is centred around the introduction of electrical heating into area IV. Both direct and storage electrical heating will be considered, the latter being a hitherto unused form of heating in Denmark. The group will evaluate the consequences which an increased use of electrical heating in area IV might have for the power generation and distribution system. In addition, the group will consider the possibilities for load management and the integration of wind power into the electricity supply system.

2.3.3. Electricity demand forecasting

Finally, ESG is involved in a small group whose functions is to update the background for the electricity-demand forecasts made for Energy Plan 81. The work of the group is primarily of a statistical nature, namely the processing of the results of a survey of household electrical appliance ownership and use. ESG participated in the formulation of the questionnaire for the survey which was part of a Danish Statistical office "Omnibus" survey.

3. INTERNAL PROJECTS

3.1. The Danish Energy System Model - DES

The DES-Model is designed for a long-term description of the Danish Energy system. Given a set of forecasts for the demand for useful energy and a development plan for the conversion and distribution system, the model calculates the annual primary energy requirement together with the fuel costs, and the costs of investments, operation, and maintenance for the energy system.

The DES-model has been used by ESG for several studies of the Danish energy system during the last 4 years. These include the evaluation of the various energy consumption scenarios and the energy supply system defined in the Danish Energy Plan 1981[1), as well as partial studies of the Danish energy system, e.g. the introduction of electrical storage heating in areas without CHP and natural gas[2), and the economic consequences of the introduction of nuclear power in Denmark[3).

In 1982 the model was used for estimating the regional distribution of the demand for space heating and the heat supply system for the study of the introduction and penetration of coal-fired district heating (see Section 2.1.).

The main effort in 1982 has been to redesign the model structure in order to provide the policy-maker with a flexible and easily understandable tool for translating energy demand forecasts into primary energy requirement and its economic consequences. The model now consists of modules describing data and submodels for the various sectors of the energy system, which allow the model to be used for partial as well as comprehensive studies of the energy system.

The computer program for the model contains the elements and facilities for building a model-structure. The program is a mixture of an interpreter, which handles simple arithmetic expressions written by the user, a collection of functions describing more complex relations, and a database-handling system with input and output facilities. The elementary unit of the system is called an account, and for each account annual values are stored for a number of years. The specification and instructions given by the user are stored in a system of files.

The model structure may be of a high degree of complexity consisting of separate modules with suitable interface accounts, whose values may be added, subtracted, or transferred from one module to another.

The functions that are included in the program are relations between two or more accounts for a single year or the whole planning period, e.g. calculation of present values of future payments. The most complex of these functions is the simulation model for electricity and CHP. This function requires data giving a detailed description of the electricity generating system:

- the total demand for electricity and its variations
- the demand for heat in each heat region, i.e. areas with a district heating grid supplied by CHP
- fuel prices
- for each power station: parameters for fuel type, maximum power, efficiency, availability, operating costs, heat production, and heat region.

The simulation gives as results the electricity production and running costs of groups of power stations for each fuel type, and the heat production in each heat region.

Each module of the model is divided into model-phases, which are logical units consisting of any of the elements mentioned above. A phase may be calculated separately or in line with other phases.

3.2. A simulation model for CHP production systems

A model for the simulation of combined heat and power production has been developed within ESG. The work is performed as a Ph.D. project in collaboration with the Electric Power Engineering Department at the Technical University of Denmark. The model may be used for a detailed evaluation of expansion plans, or for an investigation of the value of various single components in the system such as a back-pressure power plant or heat storage. The power produced by wind generators may also be incorporated by subtracting this power from the demand, and in this way the fuel savings can be assessed. Likewise, the method will give some information on whether wind-generated electricity replaces base- or peak-load production.

The model incorporates the simultaneous heat and power production at cogeneration plants, condensing power plants, and boilers, with the possibility of including heat storage units. The demands for electricity and heat are represented by time series. For a given system of heat and/or power producing units the model finds the operation strategy which, at minimum cost, will satisfy the heat and power demand.

In order to minimize the costs, the heat load dispatching in a certain time interval is carried out by demanding that all heat producing units within a single heat area must have the same marginal cost of heat production. The optimization of the operation of a heat storage will distribute the production over the time intervals in such a way that the marginal cost is time independent. A time-varying price for the co-generated electricity is included in the computations, as are the losses from the heat transmission system.

The simulation of the power production includes both unit commitment and load dispatching. This brings about the requirement (in mathematical terms) of minimizing a cost function which depends on both integer (zero-one) and continuous variables. For this purpose a "Branch-and-Bound" method is used. A subproblem of this optimization consists of the dispatching of the power production among the plants. For a given unit commitment, this is done by making the plants deliver their production to the consumer at a common marginal cost.

In the simulation model the power plants are described by a cost of minimum load, a piecewise linear incremental cost curve and start-up costs which depend on the length of the time period that the plant has been off load. The losses in the power transmission lines are taken into account. The time steps of the model are typically 2 hours, but may be of any length.

During 1982 the software has been tested and improved so that reasonably large problems can be handled by the model, e.g. unit commitment with 30 generators and 48 time steps. An example of the results of a model run is shown in Figure 3.1. The present version of the model will be documented during 1983, along with the necessary theory.

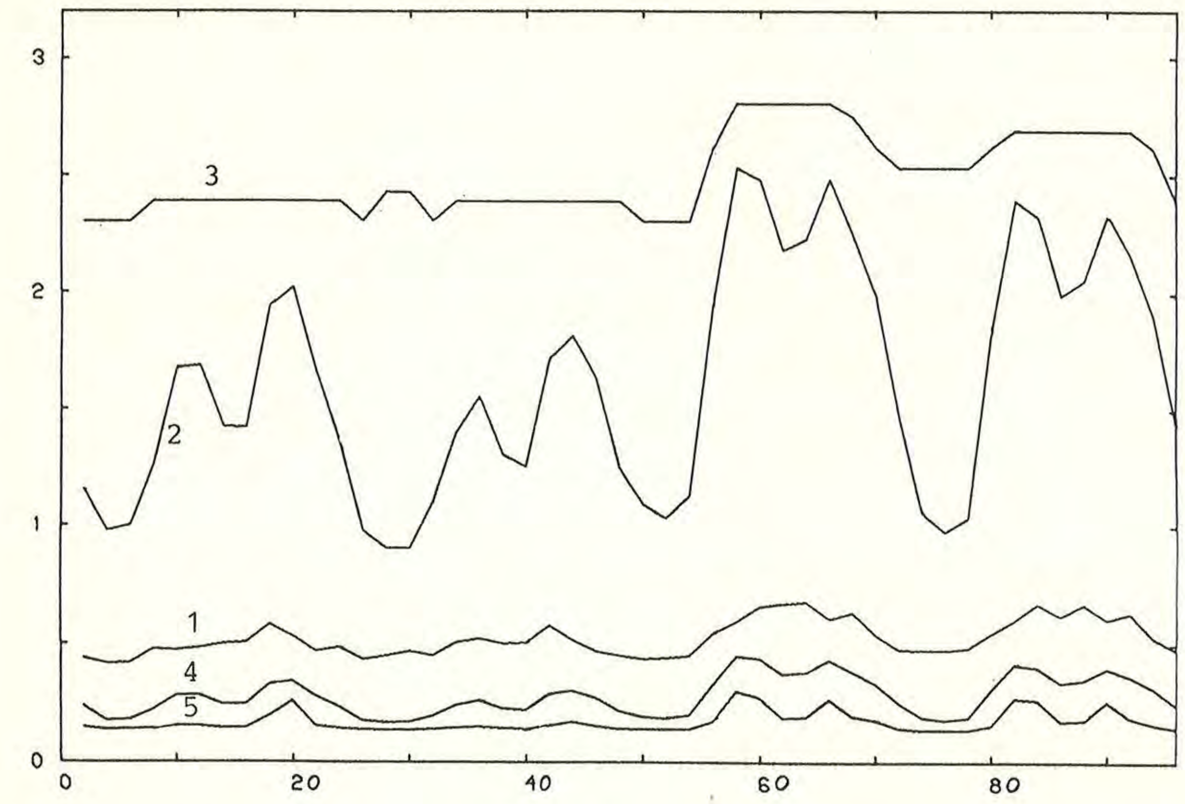


Fig. 3.1. Example of results from a run of the model.

1. Minimum pover production from CHP units (GW)
2. Power demand (GW)
3. Rated capacity of running generators (GW)
4. Production costs (Mkr/h)
5. Marginal cost of power production (kr/kWh)

3.3. Pricing policies and tariff structures for space heating

The aim of the study is to investigate the technical, economic, and political factors involved in the implementation of the Danish Heat Plan, with particular emphasis on the prices charged for the various heating forms such as natural gas, district heating, etc.

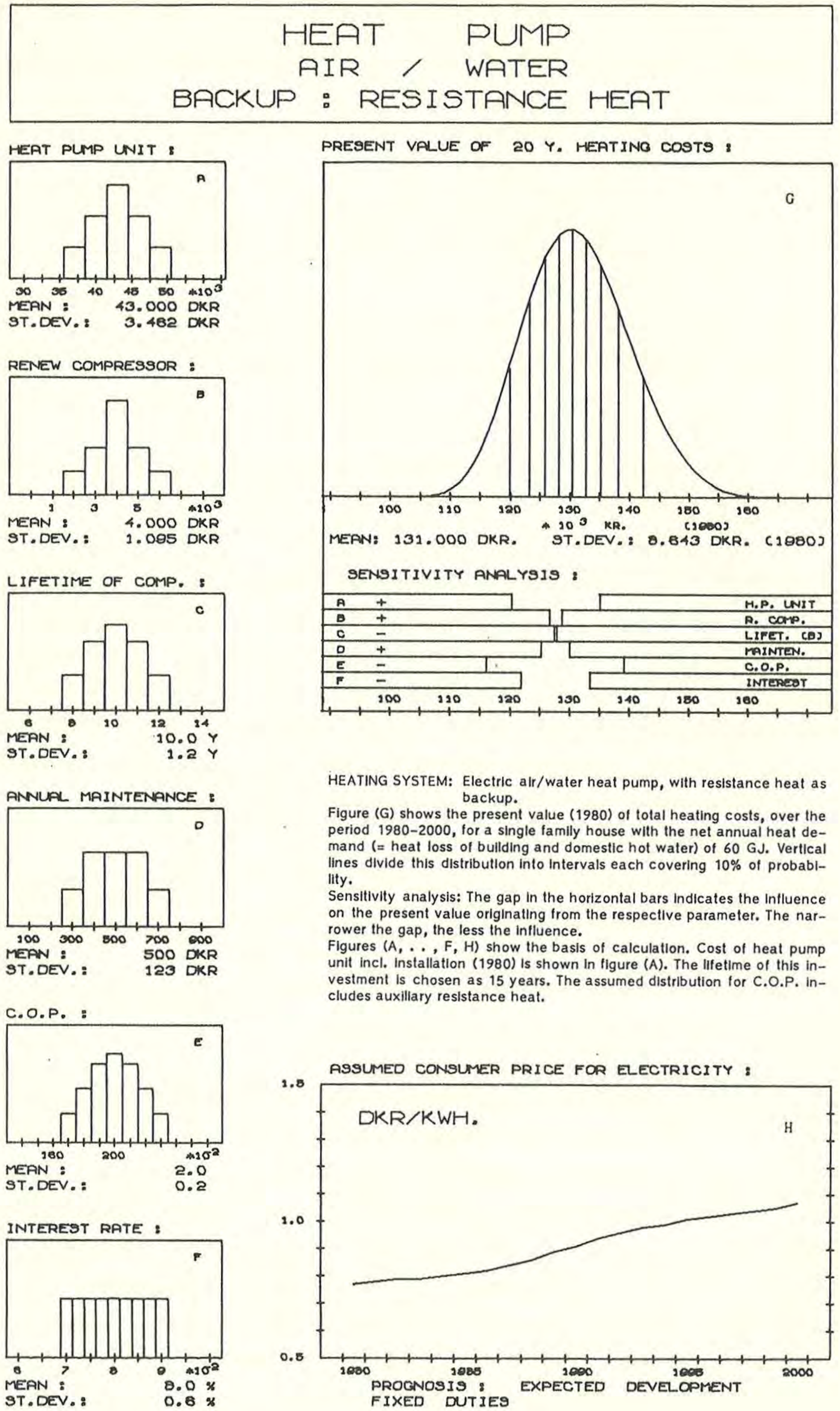
A historical study of the public authorities regulation of the pricing and investment decisions in the utilities has been carried out. In addition, a survey of the Danish planning laws has been made as well as a study of the way in which the Heat Supply Law is administrated by the public authorities today. From these studies it has been concluded that the political and legal factors involved in the implementation of the Heat Plan represent very important constraints on the pricing and investment decisions in the utilities. In order to investigate the consequences of various feasible regulation policies, the work in 1982 was concentrated on a study of the interdependence of the political/legal and technical/economic factors involved in the implementation of the Heat Plan. The project will be completed by April 1983.

3.4. Economic assessment of energy technologies.

This project which was initiated in August 1981 is aimed at assessing the economics of various energy technologies primarily in the field of renewable energy. Particular emphasis has been put on developing a method of calculation which takes into account uncertainties. To this end we have set about constructing a system of software for the calculation of economic quantities such as present value of lifetime costs for single systems and difference investments, the effective energy price and internal rate of return on the investment.

By the end of 1982 computer programs had been developed to calculate the present value of total energy and investment costs of a system. Figure 3.2 shows an example of part of the output of the present value calculation for a selected technology. The calculated probability distribution of the present value is based on uncorrelated statistical data and/or assumptions uncertainties made by the assessor. A selection of the basis of calculation is presented in Figures 3.1 (A-F).

A measure of the relative impact on the width of the present value distribution due to single parameters is indicated in Figure 3.1 (G) below the distribution. This diagram is based on a traditional sensitivity analysis. Here the present value is evaluated with fixed parameters chosen as the average values of the data distributions, and the effect of variations $\bar{x}_i \pm 2\sigma(x_i)$ is expressed as the central gap in the horizontal bars.



HEATING SYSTEM: Electric air/water heat pump, with resistance heat as backup.
Figure (G) shows the present value (1980) of total heating costs, over the period 1980-2000, for a single family house with the net annual heat demand (= heat loss of building and domestic hot water) of 60 GJ. Vertical lines divide this distribution into intervals each covering 10% of probability.
Sensitivity analysis: The gap in the horizontal bars indicates the influence on the present value originating from the respective parameter. The narrower the gap, the less the influence.
Figures (A, . . , F, H) show the basis of calculation. Cost of heat pump unit incl. installation (1980) is shown in figure (A). The lifetime of this investment is chosen as 15 years. The assumed distribution for C.O.P. includes auxiliary resistance heat.

Fig. 3.2.

It is hoped that this form of presentation and operation can prove to be a useful tool for decision makers in the evaluation of the economic consequences of the development of particular energy technologies.

A report on the project will be available in mid- 1983.

3.5. Space-heating forms and insulation levels

According to the current plan for space heating, about two-thirds of the dwellings in Denmark will be supplied either by natural gas or CHP district heating by the year 2000. In the case of the latter heating form the costs of investment in the distribution system far outweigh the operating costs for producing heat. It can therefore be questioned whether it is worthwhile to invest in further insulation of buildings supplied by CHP district heating when the sole advantage is a small reduction in primary energy consumption. On the other hand, buildings supplied by heating forms with low investment costs where the fuel costs dominate can benefit greatly from further investment in insulation.

In 1982 ESG initiated an investigation of the economics of insulation measures in relation to heating form. The work took the form of a pilot-study and was carried out primarily by a visiting researcher.

The payback times for a number of insulation measures were calculated using typical costs for insulation and for the various heating forms. Among the insulation measures considered were weather stripping, double glazing, roof insulation and cavity-wall insulation. The space-heating forms considered were district heating by CHP and oil-fired boilers, natural gas and oil central heating, and electrical heating. An example of the possible range of payback times for retrofit insulation in a single-family house is shown in Table 3.1 along with the assumptions for fuel costs and efficiencies. The variable component of the district heating tariff can vary throughout

the country by a factor of two to three depending on the pricing policy of the individual district heating companies. For the present study we have assumed prices based on the primary energy price with the efficiencies at each stage taken into account.

Table 3.1. Basic assumptions and results for a number of insulation measures carried out in a single-family house supplied with 5 alternative heating forms.

	Heat Efficiency Factors			Fuel Costs Kr/GJ		
	Plant or furnace μ plant	Distr. efciency μ network	Efficiency of use in houses μ house	Primary incl. V.A.T.	Delivered incl. V.A.T.	Useful incl. V.A.T.
Fuel Type	2.0	0.80	.92	24	15	16
CHP	0.85	0.80	.92	58	85	92
District Heating	0.8	1.00	.92	73	73	99
Natural Gas	0.72	1.00	.92	90	90	136
Electricity	0.36	0.9	1.00	70	215	215

	Payback years for insulation measure				
	Roof 200mm to 0mm	Roof 100mm to 100mm	Wall fiel cavity 80mm	Window 1 glass to 1 glass	Roof 100mm to 0mm
Fuel Type	16	135	28	48	44
CHP	3	23	5	8	8
District Heating	3	5	4	8	7
Natural Gas	2	8	3	6	5
Electricity	1	8	2	4	3

Calculations were also done for the potential energy savings and the necessary investment for the entire Danish housing stock. The results showed that for single-family dwellings the adoption of a differentiating policy, i.e. insulating buildings according to actual fuel costs, could save as much primary energy as when a uniform price is used for investment decision, and at significantly lower cost. If a uniform price is used for investment decisions then there is over-investment in CHP areas, and under-investment in areas using electrical heating. For multi-family dwellings on the other hand, significantly lower energy savings would be achieved by differentiating (or 'regionalisation') with respect to heating form. However, the increased savings obtainable with a uniform fuel price are gained at the expense of greatly increased investment with low marginal rates of return.

Although the results of the study seem to indicate that some form of differentiation of insulation investments could be advantageous, no firm conclusion can be drawn at present. One reason is that the present study assumed that the heat plan had already been implemented, but this will not be the case for over a decade. This means that insulation in many buildings now heated by oil can be repaid before conversion to cheaper forms of heating. Other factors which must be taken into account are urban renewal, building maintenance, and the difficulty of administrating non-uniform standards.

It has not been decided whether a major study in this field should be undertaken. However the results of the study are important for the further elaboration of the space-heating module of the DES-model. In addition the results of the study will prove useful in connection with ESG's participation in the reference group for a study of the energy requirements of space heating being carried out by the Danish Building Research Institute.

3.6. Databases and other supporting activities

The collection and processing of statistical data is an important task which must be undertaken in most energy planning projects. This concerns not only data for energy consumption and supply, but also macroeconomic figures, data for production in various branches, etc.

During the past years ESG has established and maintained databases and developed software for data retrieval and processing. At present ESG maintains the following databases:

1) The Danish Statistical Office (DS) National Accounts Department's Input-Output tables for 1966-79 classified into 117 branches, 66 consumption groups, and 9 final use categories.

2) DS's energy balances classified according to 117 branches and 23 energy types for 1966-79.

3) DS's investment figures distributed on investing branches classified into 51 branches and 4 types of investment for 1966-76.

4) DS's employment data classified into 117 branches and 5 types of employment for 1966-79.

These databases make up an essential part of the resources which ESG has at its disposal for developing and updating the CEC energy models (see Chapter 4.).

The DS Energy Balances are complemented by the addition of statistics from the Danish Energy Agency (ENS) and the Danish Association of Electricity Supply Undertakings (DEFU) for energy and electricity for the years 1966-81.

Finally, during the past year ESG has developed a small database of the Danish district heating system consisting of:

i) an extract from the building and dwelling register (BBR) containing information on building areas, building use and heat installations for each municipality, and

ii) published or estimated data on capacity, heat supply, and fuel consumption for each district heating company.

This database was used to describe the structure of district heating for the study of small- and medium-sized coal installations (see Section 2.1) and the Nordic heat supply study (see Section 5.2.).

4. EUROPEAN COMMISSION ENERGY-ECONOMY MODELS

The Energy Systems Group is responsible for the Danish implementation and application of four separate models as part of the energy modelling programme of the Commission for the European Communities. These are the medium-term energy demand model, the long-term energy demand model, the energy-flow optimisation model and the macrosectoral model. Details of all these models, except the latter, are to be found in the publication "Energy Models for the European Community" (5). Details of the macrosectoral model, which is still under development, have not yet been published.

4.1. The medium-term demand model

The medium-term demand model consists of 3 submodels: the macroeconomic model EURECA, the input-output model EXPLOR and the Energy Demand Model EDM.

During 1982 the work on the national part of the medium-term demand model was of a less extensive character than in the previous years. The work consisted mainly of the updating and revision of several minor parts of the model, and preparing two case studies in collaboration with the CEC-group of experts.

The two case studies describe two substantially different situations:

1) -high economic growth
   -high rise in energy prices in real terms

2) -low economic growth
   -constant energy prices in real terms.

The preliminary results of the two case studies are shown in aggregated form in Tables 4.1 and 4.2.

Table 4.1. High growth - high price study.
Total consumption of energy by sectors, mtoe

Year	Level 1980	Growth rates (% p.a.) 1981/85	1980/90
Industry	4.59	1.9	1.3
Transports	2.76	1.7	1.9
Others	6.69	0.6	2.8
Total	14.22	1.2	2.1

Table 4.2. Low growth - constant price study
Total consumption of final energy by sectors, mtoe.

Year	Level 1980	Growth rates (%p.a.) 1981/85	1980/90
Industry	4.62	0.6	1.4
Transports	2.80	1.7	3.5
Others	6.99	-0.5	4.3
Total	14.42	0.3	3.2

The preliminary results of the two case studies indicate a total energy-price elasticity of between 0.3 and 0.4 and a total elasticity of economic growth of around 0.9.

4.2. The long-term energy demand model

Work has continued on the European long-term energy demand model MEDEE3 which simulates the evolution of energy demand over a period of 25 years. Energy demand is calculated for a set of consumption sectors which, as far as possible, are homogeneous with respect to social need or economic activity, consumer behaviour, and technological context. The model is therefore highly disaggregated and requires a very large amount of social, economic, and technical data.

MEDEE3 is not an economic model like the medium-term or macrosectoral ones. It is rather a tool which can be used to translate particular scenarios for the development of the socio-economic system into energy demand terms.

Although we have been involved in the use of MEDEE3 for a number of years, it is only recently that the software has actually been implemented in Denmark. Model runs were formerly carried out by the authors of the model at IEJE, Grenoble using a computer in France. During 1982, however, the software was distributed to other centres, initially to the CEC's computer in Luxemburg and then to certain national user groups, of which Denmark was one of the first.

Because of the programming lanquage used, it is not practical at present to implement the software on other than IBM and ICL computers. For this reason the software has not been implemented on Risø's computer, a Burroughs B7800. The software was implemented instead on the IBM 3033 at the Northern European Universities Computing Centre (NEUCC).

The local implementation of MEDEE3 has allowed a much more intimate understanding of the model which in turn has led to the detection and correction of a number of inconsistencies. These occurred mainly in the section of the model dealing with space heating and concerned, in particular, the penetration of district heating and electrical heating.

Figures 4.1 (a) to (d) show the distribution of heating forms in single- and multi-family dwellings in the 2 subregion classes corresponding to the Copenhagen region and the 3 large cities Odense, Ålborg, and Århus. The curves reproduce the general characteristics of Danish space heating policy, namely the penetration of district heating and natural gas at the expense of oil-fired central heating. The curves are not however entirely predetermined from the above plans. Rather, we have attempted to reproduce the general expectations through a combination of exogenous and endogenous factors. The shares in the MEDEE results presented here were partly exogenously specified (e.g. oil and gas in existing dwellings) and partly determined by market forces (heating installations in new

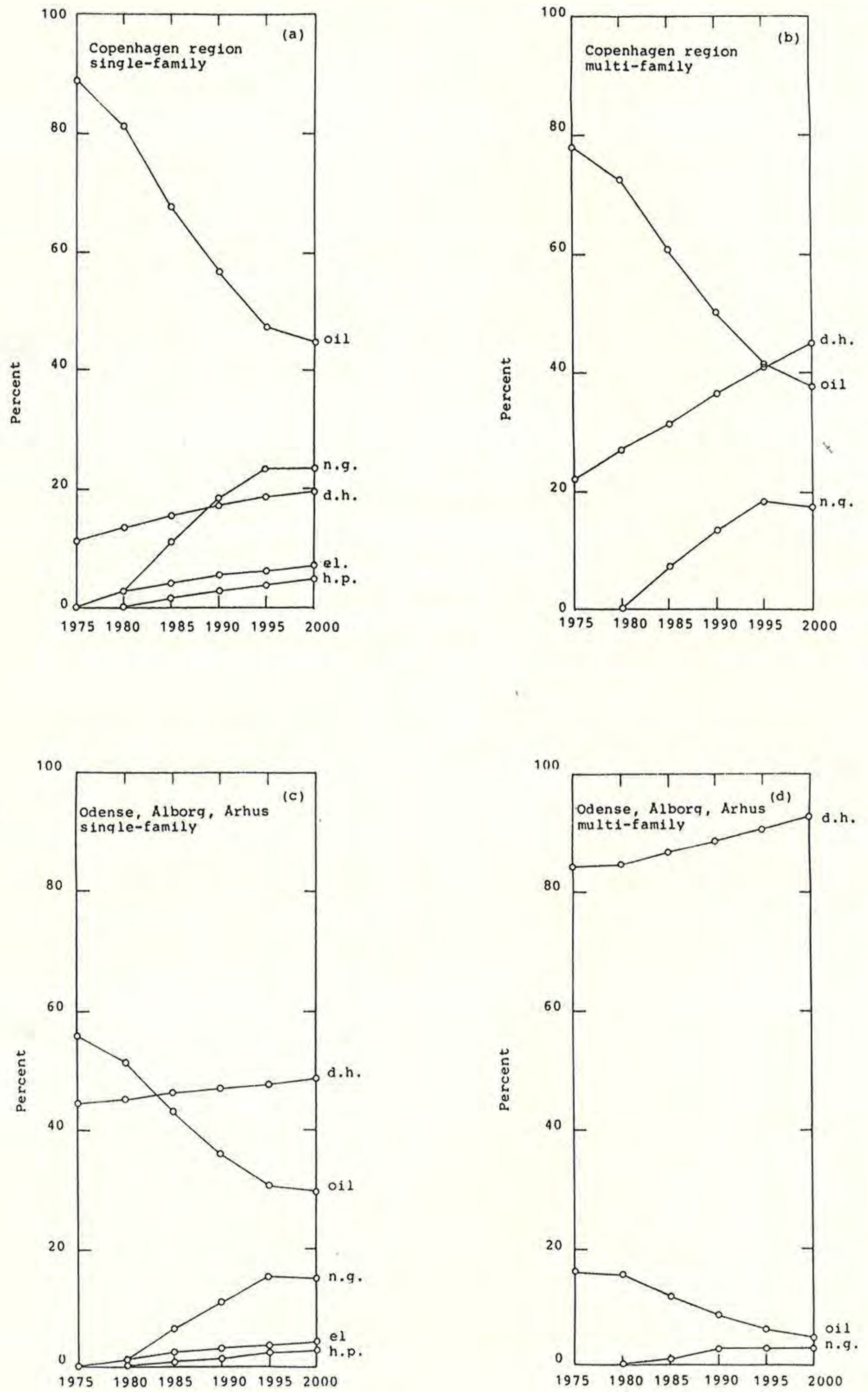


Fig. 4.1. Distribution of domestic heating forms as calculated by MEDEE 3 model for Denmark.
n.g.= natural gas, d.h.= district heating, h.p= heat pump
el.= electrical heating.

dwellings). In the case of district heating the share is determined both by market forces (for new dwellings) and by exogeneously specified penetration rates and limits (for all dwellings).

Thus, while the gross characteristics such as the penetration of district heating and natural gas are largely determined, the penetration of new heating forms such as electrical heating, heat pumps, and solar heating can vary according to other factors, such as energy prices, energy policy, and insulation levels.

Most of the work on the MEDEE3 model since its implementation in Denmark has consisted of its improvement and the correction of errors. For this purpose the model was run for the so-called reference scenario, a set of assumptions roughly consistent with the "neutral scenario" used in the Danish Energy Plan 81 (1). Towards the end of the year, however, work began on the exploration of different scenarios with regard to the evolution of energy prices. It is planned to continue the investigation of the effects of different parameter values on the model in the future, both in conjunction with the European Commission's research programme and independently as part of ESG's own research.

4.3. The macrosectoral model.

During 1982 ESG has continued working on the macrosectoral model, now called HERMES, which is a multinational macroeconomic model that focuses on energy-economy interactions and has a forecast horizon of 5-7 years.

A national model is being built in each of the EEC member countries and all of them will be interlinked by a system of bilateral trade flows. While the national models are being developed by national teams, the trade system will be drawn up by the Commission of the European Communities.

The model consists of 5 major components, to be linked together by overall national account relations. The 5 parts are the following:

1. a production part that describes the production in each of the 9 branches as a function of capital, labour, energy and other intermediate inputs,
2. a consumption part that allocates the total consumption into different categories of consumer goods via a consumer demand system,
3. an energy substitution part that splits the energy consumption in each of the production branches into different fuel types,
4. a price and income part that describes the price formation as well as the price-wage spiral, and
5. an international trade flow model that studies the trade flows in view of the underlying demand and supply structures.

In 1982 the work was centered on preliminary estimations of the consumption and energy substitution parts and on the establishment of a complete database.

The estimation of the energy substitution part has been carried out on the basis of two different models, both dealing with the choice of the optimal fuel mix, taking total energy consumption as given exogeneously. Estimates of own- and cross- price elasticities were obtained for 6 different fuel types (coal, crude oil, petroleum products, gas, electricity, and district heating) in each of the 9 production branches. The estimates obtained, which were almost independent of the model used, confirmed that the possibilities for inter-fuel substitution vary greatly among the branches.

As far as the consumption part is concerned, three different consumer demand systems have been used to study the allocation of total private consumption over 15 different commodity groups. These three systems were compared using a number of statistical tests and with regard to the estimates which were obtained for income and price elasticities.

The work programme for 1983 includes preliminary estimations for the two remaining parts of the model, completion of the database, and the final determination of all parameters in the model.

4.4. The energy flow optimisation model

The energy flow optimisation model EFOM is the supply part of the Commission's energy model complex. It uses the technique of linear programming to find the optimal energy supply structure that satisfies a given demand vector.

During 1982 the model was used for a case study called "Candidate technologies to relieve the European energy system". The aim was to calculate the rate at which certain new energy technologies would penetrate into the energy system. One of the basic results of the study was defining the level of activity attained by the new technologies. Also of interest was the order of priority for the penetration of the different technologies. This classification was done by investigating the influence of each new technology on the objective function of the problem using the IBM procedure RANGE. This procedure defines the variation in the cost of the objective function produced by a change in the capacities of new technologies.

The results of four different scenarios are tabulated in Table 4.3. These senarios consisted of one in which a global optimum was achieved, the two scenarios MIN IMPO 1 and MIN IMPO 3, in which total energy importation costs were reduced by 1% and 3%, respectively, and a nuclear moratorium situation.

When interpreting the results it should be remembered that a number of problems are recognised as far as the use of EFOM as an energy planning instrument is concerned. Examples of these are the difficulty of interpreting the results because of the

Table 4.3. Comparative analysis of the penetration of the new technologies in the different scenarios.

Process	Global optimum	MIN IMPO 1	MIN IMPO 3	Nuclear moratorium
Biogas	1	1	1	1
Collective straw firing	2	2	2	2
Individual straw firing	3	3	3	3
Geothermal energy	4	5	5	4
District heating	5	6	11	5
Collective heat pumps	6	8	7	8
Large wind turbines	7	4	4	6
Small wind turbines	8	7	6	7
Photovoltaics (decentralised)	9	11	10	10
Photovoltaics (centralised)	10	9	8	11
Wave energy	11	10	9	9
SNG	12	12	12	13
Individual heat pumps	13	13	13	13
Individual solar heating(backup)	14	14	14	14
Individual solar heating (oil)	15	15	15	15
Collective solar heat.(el.backup)	16	16	16	16

model's complex structure, inappropriate sector divisions for Denmark, and a high degree of dependence on economic and technical data which are often difficult to obtain and require frequent updating. In addition to these problems, there is some doubt as to the value of using the linear programming method, and optimisation techniques in general, for the study of a future national energy supply system. In view of these considerations, our attitude to the EFOM model as a planning tool is somewhat sceptical. It is felt that a simulation approach would be more appropriate.

5. OTHER EXTERNAL PROJECTS

5.1. Nordic Energy Systems Analysis

None of the Nordic countries, except Norway, has sufficient energy of all types to make it independent of imports, at least with present technology. However, all the countries possess some resources: Iceland, Finland, Norway, and Sweden have hydropower, Denmark and Norway have gas and oil, and Finland and Sweden have peat. This situation provides the background for a recent decision to carry out a study of the energy systems in the Nordic lands, both for each one in isolation and for a unified energy system taking into accont all the benefits which such a combined system could have for the maximizing of economy and security of supply.

The study was proposed as a collaborative effort among the national laboratories of Denmark (Risø), Finland (VTT), Norway (IFE), and Sweden (Studsvik). Iceland did not participate in the working group due to lack of capacity at the present time. Funding was supplied by the Norwegian Department of Oil and Energy and the study was formally organized by the Nordic Council.

As the study was regarded from the outset as rather ambitious it was decided to start with a preproject. The aim was firstly, to make an overview of the existing energy plans, statistics, models, and methods, and secondly, to make a proposal for a main project, in which subjects found interesting during the preproject would be studied more closely.

The preproject was carried out during 1982 and the final report completed in December. The main subjects treated in the work were an evaluation of the energy resources in the Nordic countries, a comparison of the individual energy system, a comparison of the energy plans and prognoses, both methods, and models, an evaluation of internordic trade in energy and energy containing goods, and a proposal for a main project based on the findings of the preproject.

The work was carried out by members of the participating laboratories. In addition to the plan outlined above, a database was set up. This includes all relevant statistics of the countries, e.g. energy supply and consumption, both historical and projected.

The main results of the study may be summarised as follows:

- The goals of the energy plans and of the research and development programs are very much alike,
- the methods used in the statistics and the prognoses are somewhat different,
- each country's foreign trade in energy products is large but inter Nordic trade is small, and
- the total energy resource in the Nordic countries is great enough to make the region as a whole self-supplying

Because of the last point it was agreed that the main project should concentrate on a search for ways in which the regions can benefit from its total resource of energy.

5.2. Nordic heat supply study

During the summer and autumn of 1982 a prestudy of the Nordic heat supply system was carried out as a joint venture with Studsvik AB of Sweden, the Technical Research Centre of Finland and the Electricity Supply Research Institute of Norway. The prestudy was initiated by the Nordic Council of Ministers.

The main objective for the study was to investigate the extent to which further Nordic cooperation would be advantageous to the Nordic heat supply system, and to identify the areas where this would be possible.

Within the restricted frame of a prestudy it is impossible to cover all aspects of the heat supply systems, and priority was accordingly given to the following three areas:

<u>The structure and development of the heat supply system in the four countries.</u> Some of the geographical and institutional reasons for the considerable differences between the four national systems are described. It is shown that the differences became greater after the oil price increase in

1973. Because of the different degree of dependence on oil, the rate of substitution towards other fuels varied among the countries. In the long run a leveling out is foreseen and the four national systems may eventually become more uniform than ever before in modern times.

Heat production for district heating. At the present time the utilisation of district heating varies from 42% of the energy consumption for heating in Denmark to 1% in Norway. All four countries have extensive plans for expansion of district heating but from different sources. The different fuels and the techniques for burning them are described, as is the utilisation of large electrically driven heat pumps for district heating.

Pricing and measuring techniques for electricity and district heating. The daily and seasonal variations for these two energy distribution systems are alike on the consumer side. The costs for meeting the variations will depend on the production system involved. The different approaches in the four countries are described.

5.3. Windpower in the Faroe Islands and Iceland

A preproject on the introduction of windmills to an electricity supply system presently based on diesel generators and hydropower has been carried out. The project was carried out in collaboration with the Energy Council in the Faroe Islands and the State Electricity Supply Company of Iceland, under the auspicies of the Nordic Co-operative Organization for Applied Research (NORDFORSK).

The study covered the major Faroe Island electricity supply system as well as two small isolated islands. At the present time the main electricity supply system in the Faroe Islands has an installed capacity of about 40 MW of which 14 MW is hydropower and 26 MW is supplied by diesel generators. The hydropower is based on fairly small reservoirs with capacity

for only a few weeks use, so that no seasonal storage is possible. However, in an electricity supply system of this size it should be possible to make use of several megawatts of windpower if the wind climatology, the specification and siteing of the windmills, and the supply-demand situation are well analysed and a suitable operating strategy is chosen.

For the small islands included in the study the situation is somewhat different, and in many ways much more complicated since the installed capacity is only a few hundred kilowatts, supplied by diesel generators. If windmills were introduced in such small systems they would make up a much larger percentage of the installed capacity than in the large system. For this reason a very detailed analysis is needed.

The study included:

- assessment of the present energy supply system
- analysis of demand prognoses
- identification of the main factors to be included in a computer simulation program to optimize the system
- preliminary considerations concerning windmill siting.

The results of the preproject were recommendations for the development of a computer simulation model for the simulation of the whole electricity supply system, and for wind measurements to be carried out in conjunction with the establishment of a windmill programme.

5.4. Assessment of the technical and economic prospects for wind energy in the EEC countries

In March 1981, the Advisory Committee for Program Management for the CEC's solar energy programme initiated a study of wind power. The Energy Systems Group was awarded a contract to carry out part of the study, namely the assessment of the technical and economic prospects for windpower in Denmark.

The first part of this study consisted of an evaluation of the number of possible sites for large energy converters. The evaluation took account of physical, legal, and political constraints on land use.

The technique suggested by the European Commission was the "Statistical Grid Method" which involves the use of a division of the country into areas with equal wind speeds. These wind speeds are based on measurements from different meteorological stations and are only representative for the immediate surroundings. The observations cannot therefore be taken as representative of the wind conditions in a region.

In view of the shortcomings of the Statistical Grid Method and as a comprehensive investigation of wind resources in Denmark had already been carried out by the National Agency for Physical Planning (5), it was decided to use the latter as the basis for the present study.

Another of the tasks carried out under the contract was the collection of Danish recommendations for Research and Development in wind energy. This collection is to be used in the formulation of the next CEC programme for research and development in solar energy to cover the period 1983-87.

6. PUBLICATIONS AND LECTURES

6.1. Publications

P.E. Grohnheit	"Omkostninger ved byfornyelse og byudvikling" (Economic assessment of urban renewal and growth) Planstyrelsen (National Agency for Physical Planning) Copenhagen, 1982.

P.E. Grohnheit and P.S. Christensen	"The DES-Model. A simulation model of the Danish energy System" Risø-M-2355, Risø National Laboratory, 1982.
H.Larsen	"Danish energy planning after 1973 and its implementation" Report No 11, The European Energy Scene. The Watt Committee on Energy, London, 1982.
G.A. Mackenzie	"Application of the long-term energy demand model to Denmark" EUR 8036. 163p.
P.E. Morthorst	"Energy models for Denmark. EXPLOR-EDM". EUR 8051. 22p.
E.V. Pløger	"Input-output analyse af udviklingen i erhvervenes energiforbrug 1966-75". (Input-output analysis of the development of industrial energy consumption 1966-75) Nationaløkonomisk Tidskrift, 120 nr. 3 (1982), 275-288.

6.2. Lectures

F.M. Andersen	"Description of a macrosectoral model for Denmark" Meeting of Danish Econometric Society, Sandbjerg, 30 May .
F.M. Andersen and E. H. Nielsen	"Description of a macrosectoral model for Denmark" Economic Institute, Århus University, November.
P.E.Grohnheit	"Indicators of heating efficiency in Denmark", Workshop on Residential Energy Use, at Joint Research Centre ISPRA, Italy, arranged by Lawrence Berkeley Laboratory in collaboration with the Commission of the European Communities, 14-16 June.

H.V. Larsen	"Simulation of combined heat and power production", Energy Systems Analysis Seminar, held at Odense University, 25 February.
P.E. Morthorst	"Methods used for electricity demand prognoses" Elektrokonferencen 1982, Copenhagen, 5 May.
P.E. Morthorst	"Comparison of Danish Industrial energy demand with that of other EEC countries". Energy Systems Analysis Seminar, held at Technical University of Denmark, 25 November.
E.H. Nielsen	"Comments on an energy substitution model: flexible function forms and quantity summability" Meeting of Danish Econometrics Society, Sandbjerg, 30 May.
E.V. Pløger	"The choice of industrial branch classification in energy statistics" Energy Systems Analysis Seminar, held at Technical University of Denmark, 25 November.

7. STAFF

Leader:
Hans Larsen M.Sc. (DtH*), Ph.D. (DtH)
Graduated in 1970 from the Technical University of Denmark as M.Sc. in Electrical Engineering. 1970 postgraduate student at Risø, Ph.D. in Reactor Physics in 1973. From 1973 to 1976 seconded to the OECD High Temperature Reactor Project, Dragon, at AEE Winfrith, Dorset U.K. 1976-80 at Risø National Laboratory working with systems reliability and reactor core performance. Head of the Energy Systems Group from July 1980. Member of a number of national and international committees: a working group dealing with long-term energy planning for the Danish Ministry of Energy, Advisory Committee on Energy, for the Danish Association of Electrical, Chemical, Mechanical and Civil Engineers European Commission ACPM on Energy Systems Analysis and Strategy Studies, Danish National Committee of World Energy Conference. In 1982 involved in project on Long Term Prospects of Energy Technologies and in the Faroe Island project.

Deputy leader:
Poul Erik Morthorst M.Econ, (Århus).

Economist specialised in econometric forecasting. Research assistant at Institute of Economics, Århus University from 1976 to 1977. Joined ESG in June 1978. Main activities within ESG include the implementation of the CEC medium-term model and general government energy planning, especially forecasting of electricity demand. Involved in project on Scandinavian energy system analysis. Working with economics of renewables and member of advisory group set up by the Energy Agency to study renewable energy in rural communities. Member of working groups set up by Ministry of Energy to study electrical heating in areas not served by CHP and natural gas.

Permanent staff:

Frits Møller Andersen M.Econ. (Århus).

Economist specialised in computer modelling and econometrics. Worked as teaching assistant in the Institute of Statistics, Århus University and as economic planner in local government before joining ESG in May 1980. Main activities within ESG consists of the development, implementation, and use of econometric models for energy demand forecasting, in particular the development of the macrosectoral model.

Peter Skjerk Christensen M.Sc. (DtH).

Physicist with previous experience in reactor physics in the Reactor Technology Department, Risø, before joining ESG as a founding member. Activities within ESG include modelling of electricity and heat production and transmission systems, modelling of total energy systems, and maintaining an up-to-date knowledge of the construction and operation of power reactors and of the nuclear fuel cycle.

Jørgen Fenhann M.Sc. (Copenhagen).

Physicist with mathematics and chemistry as subsidiary subjects. After 1 year of teacher training taught at high school and DtH. Since July 1977 worked on the CEC energy supply model EFOM, first with the Niels Bohr Institute, University of Copenhagen, and since November 1978 with ESG. Activities within ESG include the survey of energy studies involving windpower, long range technological forecasts, energy for rural areas and energy statistics.

Poul Erik Grohnheit M.Econ. (Copenhagen).

Economist, before joining ESG worked with the Danish Buildings Research Institute (1969-71), as a town planning consultant (1971-72 and 1979-80) and on economic planning in local government 81973-79). Joined ESG in May 1980. Main interests within ESG include energy economics, town planning, local government, space heating and the economic andlysis of power generation systems.

Niels Kilde M.Sc. (DtH).

Graduated in 1962 as chemical engineer with special emphasis on metallurgy. Master's thesis on industrial galvanising. From 1962 to 1981 employed at the Danish Steelworks Ltd., Frederiksværk as deputy department manager in the laboratory (1962-67), personal assistant to the technical director (1967-72), department manager for production and head of planning and implementation of new continuous casting plant (1972-77). During the final period, as development and energy manager (1977-81), responsible for the reconstruction of electric arc furnaces and the utilisation of cooling water for the heating of the entire works and the district heating of the neighbouring town of Frederiksværk.

Joined ESG in September 1981. Activities include long-term energy planning, coal technology, Scandinavian heat planning and industrial energy use. Member of the Danish Energy Ministry's steering group for energy R&D in industrial processes.

Gordon A. Mackenzie B.Sc. (Edinburgh), Ph.D. (Edinburgh).

Physicist with experrience in experimental condensed matter physics. First came to Denmark 1974 to participate in physics experiments at Risø. Postdoctoral work in Physics Depart,ent, Risø 1976-78. Lecturer in physics at Edinburgh University 1978-79. After a further period at Physics Department, Risø, joined ESG in Febuary 1980. Main activities within ESG include the operation and maintenance of the MEDEE3 model, use of the DES model, participation in the Faroe Islands project and a member of administrative tasks involving public relations.

Jørgen Marstrand M.Sc. (DtH), D.Techn. (DtH).

Mechanical engineer with experience in the shipbuilding industry and the Danish factory Inspectorate before joining Risø in 1957. Doctoral thesis "Methods of Hydrodynamic Computation of Ship Propellers" published in 1952. Former head of Engineering Department at Risø and chairman of the Safety Committee for the DR2 reactor. Played a leading role in the design and construction of various installations at Risø, including the Hot Cell. Contributions within the field of reactor technology include the invention of a new type of fuel assembly for boiling-water reactors employing a hexagonal arrangement of fuel rods and twisted deflectors. Active participant in the public debate on future energy sources and the role of nuclear power. Worked with the Reactor Technology Department, Risø, before being associated with ESG in 1980. Recent activities have included the collection and examination of technical and economic data for energy conversion systems and participation in the project on long-term technological development.

Erland Hejn Nielsen M.Math.-Econ. (Århus) (until September)

Mathematical economist specialised in economic modelling and econometrics. During period of study worked as programming assistant at the Institute of Economics, University of Århus. Joined ESG in June 1981. Main activities within the Group are the development and implementation of the EC Macrosectoral Model.

Ellen V. Pløger M.Econ (Copenhagen).

Economist specialised in economic modelling and econometrics. Worked in the Danish Statistical Office on national accounts, energy balances and input-output models before joining ESG in November 1982. Main activities within the Group are the development and implementation of the CEC Macrosectoral Model (HERMES).

Postgraduate Students:

Henrik Andersen M.Sc. (DtH), B.Com. (HHK*)

Mechanical engineer with postgraduate qualification in economics. From February 1978 until September 1979 worked at DtH on estimate of design parameters for cooling towers at the Mechanical Engineering Department and the Danish Solar Heating Programme at the Thermal Insulation Department. Awarded a scholarship by Danish Council for Scientific and Industrial Research to work on the study programme on energy and economics, project on pricing policies and tariff structures in space heating begun October 1979.

Helge V. Larsen M.Sc. (DtH).

Graduated in electronic engineering in 1974 and subsequently worked as a university demonstrator at DtH and as an electronic engineer in industry. Joined Risø National Laboratory in 1976, engaged in computer modelling of radiation heat transfer in BWR fuel elements with the Reactor Technology Department. Later worked on Nordic project on modelling of district heating systems, based on Studsvik Energiteknik, Sweden. Currently developing a model for the simulation of power station operation.

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Research Fellow:

Lars Henrik Nielsen M.Sc. (Copenhagen).

Physicist with mathematics as a minor subject. Master's thesis described a model for a solar heating system with a central heat storage combined with a district heating system. Worked as high school teacher and teaching assistant at the University of Copenhagen during period of study. Joined ESG in August 1981 as research fellow. Currently working on a model to describe the economic characteristics of renewable energy technologies.

Consultants:

Peter Laut, Professor, Engineering Academy of Denmark.

Visiting Researchers

Hugh M. Clyne B.E.(N.U.I.),M.I.C.E. (U.K.)
Head of Building Energy Department at the Institute for Industrial Research and Standards, Dublin, Ireland. Worked in ESG during August and September 1982 on the study of insulation levels and space-heating forms.

Ian C. Haunamm B.Sc. (Strathclyde), M.Sc. (Strathclyde).
Member of Energy Studies Unit at the University of Strathclyde, Glasgow, Scotland. Worked in ESG for a period of one month from the end of October to the end of November 1982. The main subjects of research during the visit were the long-term prospects of biomass in the Danish energy system and the long-term energy demand model MEDEE3.

Undergraduate assistant:

Jesper Schmaltz-Jørgensen

Secretaries:

Jette Larsen
Susanne Valentin Nielsen

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